

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
14 November 2002 (14.11.2002)

PCT

(10) International Publication Number
WO 02/091051 A2

(51) International Patent Classification⁷: G02B 6/30

(21) International Application Number: PCT/US02/14386

(22) International Filing Date: 8 May 2002 (08.05.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/289,627 8 May 2001 (08.05.2001) US

(71) Applicants: MASSACHUSETTS INSTITUTE OF TECHNOLOGY [US/US]; 77 Massachusetts Avenue, Cambridge, MA 02139 (US). KIMERLING, Lionel, C. [US/US]; 369 Strawberry Hill Road, Concord, MA 01742 (US). HAUS, Hermann A. [US/US]; 3 Jeffrey Terrace, Lexington, MA 02420 (US). WADA, Kazumi [JP/US]; 23 Hill Street, Lexington, MA 02421 (US). JOHNSON, Steven, G. [US/US]; 521 Longmeadow Circle, St. Charles, IL 60174 (US). MANOLATOU, Christina [GR/US]; 305 Memorial Drive, Cambridge, MA 02139 (US). MICHEL, Jurgen [US/US]; 500 Summer Street, Arlington, MA 02474 (US). NGUYEN, Trinh, Tranh [VN/US]; 20700 San Jose Hills Rd, #163, Walnut, CA 91789 (US).

(72) Inventor: AGARWAL, Anuradha, M.; 105 Hickory Road, Weston, MA 02493 (US).

(74) Agents: CONNORS, Matthew, E. et al.; Samuels, Gauthier & Stevens, LLP., Suite 3300, 225 Franklin Street, Boston, MA 02110 (US).

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— without international search report and to be republished upon receipt of that report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: VERTICALLY AND Laterally CONFINED 3D OPTICAL COUPLER

(57) Abstract: An on-chip silicon-based optical coupler used to guide light from an optical fiber to a waveguide. The incoming wave is confined vertically by stacks of graded index materials. In the lateral direction, a linear taper formed by etched holes or trenches confines the wave.

WO 02/091051 A2

VERTICALLY AND Laterally CONFINED 3D OPTICAL COUPLER**PRIORITY INFORMATION**

This application claims priority from provisional application Ser. No. 60/289,627
5 filed May 8, 2001.

BACKGROUND OF THE INVENTION

The invention relates to the field of optical couplers, and in particular to optical couplers that couple light between optical fiber and on-chip optical waveguides.

10 Integrated Optical Circuits (IOCs) have been under development for a number of years. The designers of these circuits seek to integrate several optical functions on a single semiconductor chip. IOCs generally include waveguides formed from several layers of material. For example, in a two-dimensional planar waveguide, a core layer is sandwiched between two layers of clad material.

15 There is a need to couple light from optical fibers to these on-chip waveguides and vice versa. However, there are a number of other factors that complicate such coupling. First, IOCs are typically high index-contrast systems so as to provide stronger light confinement in smaller dimensions, while optical fibers are low index-contrast systems. That is, there is a much larger refractive index difference between a
20 waveguide's core and cladding than between a fiber's core and cladding. Second, there is a mode diameter mismatch between fibers and waveguides. For example, a fiber may have a core diameter of 8-10 μ m, while a single-mode waveguide core may have a width of 0.6-2 μ m and thickness of 0.6-2.0 μ m. Lastly, there is a mode shape mismatch. Fiber typically maintains a circular mode field, while waveguides typically
25 maintain an elliptical mode field. Thus, as shown in figure 1, if a fiber is directly butt-coupled to a waveguide, high power losses occur. In figure 1 the fiber is directly butt-coupled to the waveguide at $z=4\text{ }\mu\text{m}$.

Some common fiber-to-chip coupling schemes have arisen in an attempt to overcome such losses. To confine light in the vertical dimension, prior schemes have
30 used GRIN lenses on the fiber-side or high silica graded index stacks on-chip. For example, Shiraishi et al in "*Spot size reducer for standard SMF utilizing a graded-index fiber tip*," 11th International Conference Optical Communications- Vol. 1, No. 97- pp 50-3, has demonstrated that a tip with a square-law index profile can be used as a spot size reducer. In this paper, the authors reported a method to reduce the single-
35 mode fiber spot size to 5 μ m that uses a quarter-pitch length of a graded-index fiber

(GIF).

On the chip side, a planar GRIN lens on silica has been fabricated as described by Beltrami et al in "*Planar graded-index (GRIN) PECVD lens*," Electronics Letters- 14th March 96- Vol. 32; No. 6, pp 549-50. In this paper, the author varies n around 1.44 by adjusting the F doping (CF₄ flow in oxide PECVD). The periodic refocusing effect of the parabolic profile is demonstrated. Use of doping to achieve the profile, however, prevents an index of refraction higher than 1.46.

To confine light in the lateral dimension, a laterally tapered waveguide has been used to couple from a photonic device to a single-mode fiber. However, a direct tapered structure has not been used for coupling from a single-mode fiber to a waveguide since there is no practical way to vertically taper an on-chip structure to provide vertical confinement. A lateral taper alone still results in high-coupling loss. One way to solve the problem is a tapered rib waveguide used in conjunction with a much bigger mesa waveguide underneath, as shown by Smith et al in "*Reduced coupling loss using a tapered-rib adiabatic-following fiber coupler*" IEEE Photonics Technology Letters Vol. 8, No. 8, August 96- pp 1052-4. Light is injected in the mesa, coupling up due to higher n and the tapered ridge. This device still has a size on the millimeter order.

Whatever the precise merits, features and advantages of the above cited references, none of them achieve or fulfills the purposes of the invention.

20

SUMMARY OF THE INVENTION

One aspect of the invention provides an optical coupler used to guide light from an optical fiber to a waveguide. The optical coupler comprises a vertical stack of varying refractive index layers formed on a cladding layer. The layers gradually decrease in refractive index from a top layer to a center layer and then increase from the center layer to a bottom layer formed on the cladding layer. The vertical stack has at least one pair of horizontally spaced trenches or periodic holes that increase in dimensions from a first end of the stack to a second end of the stack so as to form a tapered shape in the stack.

Another aspect of the invention provides a method of producing an optical coupler used to guide light from an optical fiber to a waveguide. A cladding layer is provided. A vertical stack of varying refractive index layers is formed by depositing layers of varying refractive index material on the cladding layer. The layers gradually decrease in refractive index from a top layer to a center layer and then increase from the center layer to a bottom layer. At least one pair of horizontally spaced trenches or periodic holes are etched in the vertical stack that increase in dimensions from a first end of the stack to a second end of the stack so as to form a tapered shape in the stack.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates the high power losses that occur if a fiber is directly butt-coupled to a waveguide;

Figure 2a illustrates a birds-eye view of a three-dimensional fiber-to-waveguide coupler according to the principles of the present invention;

Figure 2b a side view of a three-dimensional fiber-to-waveguide coupler according to the principles of the present invention;

Figure 2c a top view of a three-dimensional fiber-to-waveguide coupler according to the principles of the present invention using etched trenches;

Figure 2d a top view of a three-dimensional fiber-to-waveguide coupler according to the principles of the present invention using etched periodic holes;

Figures 3a and 3b illustrates the general design parameters for simulations of the vertical confinement for a coupler according to the principles of the present invention;

Figures 3c, 3d and 3e illustrate beam propagation simulations for differing parameters of the coupler of figure 3a with a Gaussian input wave;

Figures 3f illustrates FDTD (finite difference time domain) simulations for differing parameters of the coupler of figure 3a with a Gaussian input wave;

Figure 4a illustrates the general design parameters for simulations of the lateral confinement for a coupler according to the principles of the present invention; and

Figures 4b, 4c, and 4d illustrate FDTD simulations for the coupler of figure 4a with different lengths.

DETAILED DESCRIPTION OF THE INVENTION

The invention provides for an on-chip optical coupler used to guide light from an optical fiber to a waveguide. The incoming wave is confined vertically by stacks of graded index materials. In the lateral direction, a linear taper formed by etched holes or trenches confines the wave.

The present invention allows for a coupler to be fabricated that reduces the spot size of incoming infrared light (1550 nm) from a diameter of 8-10 μ m to less than 1 μ m when coupling such light from a single mode fiber to a single mode silicon nitride waveguide. The present invention also allows such a coupler to be on the order of one hundred microns in size.

Figure 2a illustrates a birds-eye view of a three-dimensional fiber-to-waveguide coupler 200 according to the principles of the present invention. As shown, coupler 200 is a waveguide formed on-chip that couples light from an optical fiber 204 to a waveguide 206 made of, for example, silicon nitride (SiN) or silicon oxynitride (SiON).

Waveguide 200 is formed by depositing layers of a core material having varying refractive indexes on an underlying cladding 208, which is formed on top of a substrate 210. Preferably, waveguide 206 is integrated into center layer 212, thus eliminating the out-coupling loss to waveguide 206. Referring to figure 2b, which illustrates a side view of coupler 200, the varying index layers gradually decrease in refractive index from the top of coupler 200 to the center and then increase from the center of coupler 200 towards the lower cladding. For example, a top layer 216 is (1.5x)% doped SiO₂ (doped with, for example, N). Moving towards the center, each layer is increasingly doped to increase the index until center layer 212, which is (10x)% doped SiO₂. Moving from center layer 212, each layer is decreasingly doped until bottom layer 214 on top of undercladding layer 208.

This layer is x% doped SiO₂. This vertical stack of varying refractive index layers compresses the optical mode in the vertical direction towards the middle of the structure.

Waveguide 200 also has horizontally etched trenches or periodic holes 202 that increase in dimensions from the fiber-end of waveguide 200 to the waveguide-end so as to form a tapered shape in the stack. Figure 2c illustrates a top view showing etched trenches, while figure 2d illustrates a top view showing etched periodic holes. The etched trenches or holes provide a graded effective index contrast with the highest contrast at the waveguide-end. This guides light towards the middle of the structure, laterally.

When periodic holes are used as shown in figure 2d, the periodicity (a_h , a_v) of the holes is less than half the wavelength of light in the medium to allow guided modes. Also, the dimensions (l_1 , w_1) of the holes or trenches are on the order of the wavelength of the light in the medium to avoid scattering. While the holes/trenches can be air filled, they are preferably back-filled with a solid material to provide greater mechanical stability for the structure.

Figure 3a illustrates the general design parameters for simulations of the vertical confinement for a coupler 300 according to the principles of the present invention. Coupler 300 is generally designed to couple between a silica optical fiber 302 ($n=1.46$; core diameter 8-10 μ m) and a single-mode waveguide 304 ($n=2.0$ -2.5; width = 0.8-2.0 μ m; thickness = 0.8-2.0 μ m). Coupler 300 has a refractive index increasing parabolically from 1.46 to n_{max} , where n_{max} is the refractive index of center layer 306. That is, $n(y)=n_{max}(1-y^2/2h^2)$ where y is the vertical distance from the center; and h correlates the stack thickness and its maximum, minimum indices of refraction. The normalized $n(y)$ profile is illustrated in figure 3b. Coupler 300 is 8 μ m high and has a

length less than $10\mu\text{m}$.

Figures 3c, 3d and 3e illustrate beam propagation simulations for coupler 300 with a gaussian input wave at a waist of $8\mu\text{m}$. The following table summarizes the parameters and coupling efficiency of the simulations shown in these figures:

5

	n_{max}	Δn	Center waveguide thickness (w_2) [μm]	# of layers (top or bottom)	Coupling Efficiency	Length of coupler at max efficiency [μm]
Figure 3c	2.0	0.54	1.5	5	0.85	8
Figure 3d	2.0	0.54	1.5	8	0.87	8
Figure 3e	2.5	1.04	0.8	10	0.83	6

As can be seen from the simulations, the number of graded index layers does not significantly affect the coupling efficiency. Therefore, there is a high tolerance in processing this vertical structure. Figure 3f illustrates a finite difference time domain (FDTD) simulation for coupler 300 with $n_{\text{max}} = 2.0$, 8 layers, and a length of $8\mu\text{m}$.

Figure 4a illustrates the general design parameters for simulations of the lateral confinement for a coupler 400 according to the principles of the present invention. Coupler 400 is generally designed to couple between a silica optical fiber 402 ($n=1.46$; core diameter $8\text{-}10\mu\text{m}$) and a single-mode waveguide 404 ($n=2.0\text{-}2.5$; width = $0.6\text{-}2.0\mu\text{m}$; thickness = $0.6\text{-}2.0\mu\text{m}$). Coupler 400 has tapered trenches 402 in it for lateral confinement. Trenches 402 increase in dimension from a fiber-end to a waveguide-end. The width between the trenches at the fiber-end is $8\mu\text{m}$ and $2\mu\text{m}$ at the waveguide-end. Coupler 400 is $12\mu\text{m}$ wide. Trenches 402 are air-filled.

Figures 4b, 4c, and 4d illustrate FDTD simulations for coupler 400 with different lengths. Figure 4b illustrates FDTD results for a coupler length of $10\mu\text{m}$. As can be seen, for a coupler length this short, multimode develops within the taper, causing a low coupling to the fundamental mode. However, as shown in figure 4c, when the length is increased to $25\mu\text{m}$, there is only a single mode at the taper end and approximately 0.85 power is coupled to even modes. Similarly, as illustrated in figure 4c, there is only a single mode at the fiber-end for an inverse propagation from waveguide to fiber when the length is $25\mu\text{m}$.

One of skill in the art will appreciate that the coupler can be any type of waveguide, such as a ridge, strip or channel waveguide. Also, the index grading in the

6

vertical direction can take on a number of different functions. For example, the grading function can be a parabolic, exponential, sine, cosine, or sinh function. Furthermore, materials for the vertical stack other than SiO_2 can be used, such as SiON or SiN .

5 Although the present invention has been shown and described with respect to several preferred embodiments thereof, various changes, omissions and additions to the form and detail thereof, may be made therein, without departing from the spirit and scope of the invention.

What is claimed is:

7
CLAIMS

- 1 1. An optical coupler used to guide light from an optical fiber to a waveguide
2 comprising:
3 a cladding layer;
4 a vertical stack of varying refractive index layers, wherein the layers gradually
5 decrease in refractive index from a top layer to a center layer and then increase from the
6 center layer to a bottom layer formed on the cladding layer;
7 at least one pair of horizontally spaced trenches or periodic holes in the vertical
8 stack that increase in dimensions from a first end of the stack to a second end of the stack
9 so as to form a tapered shape in the stack.
- 1 2. The coupler as per claim 1, wherein the at least one pair of trenches or holes are
2 back-filled with a material that has a higher refractive index than air.
- 1 3. The coupler as per claim 1, wherein the waveguide is integrated with the center
2 layer.
- 1 4. The coupler as per claim 1, wherein the at least one layer of the stack is made of
2 SiO₂.
- 1 5. The coupler as per claim 1, wherein the at least one layer of the stack is made of
2 SiON.
- 1 6. The coupler as per claim 1, wherein the at least one layer of the stack is made of
2 SiN.
- 1 7. The coupler as per claim 1, wherein the waveguide is made of any one of: SiN or
2 SiON.
- 1 8. The coupler as per claim 1, wherein the layers decrease and increase according to
2 a grading function that is any one of: a parabolic, exponential, sine, cosine, or sinh
3 function.
- 1 9. A method of producing an optical coupler used to guide light from an optical
2 fiber to a waveguide, the method comprising:
3 providing a cladding layer;
4 forming a vertical stack of varying refractive index layers by depositing layers of
5 varying refractive index material on the cladding layer, wherein the layers gradually
6 decrease in refractive index from a top layer to a center layer and then increase from the

7 center layer to a bottom layer;
8 etching at least one pair of horizontally spaced trenches or periodic holes in the
9 vertical stack that increase in dimensions from a first end of the stack to a second end of
10 the stack so as to form a tapered shape in the stack.

1 10. The coupler as per claim 9, wherein the at least one pair of trenches or holes are
2 back-filled with a material that has a higher refractive index than air.

1 11. The coupler as per claim 9, wherein the waveguide is integrated with the center
2 layer.

1 12. The coupler as per claim 9, wherein the at least one layer of the stack is made of
2 SiO₂.

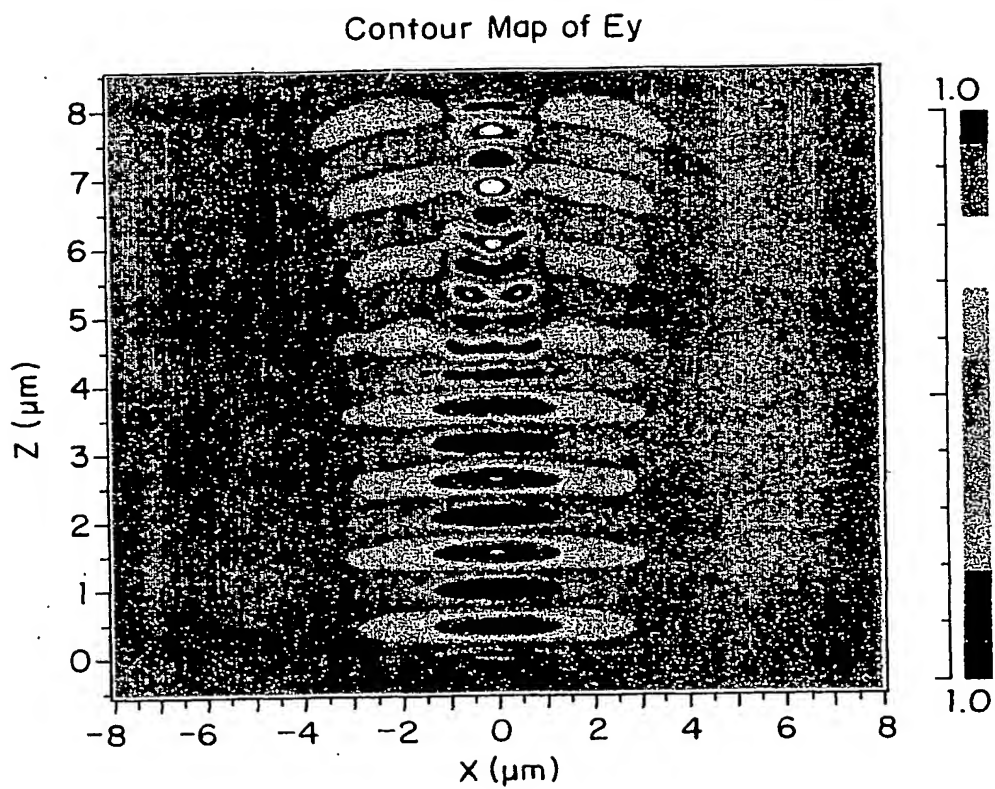
1 13. The coupler as per claim 9, wherein the at least one layer of the stack is made of
2 SiON.

1 14. The coupler as per claim 9, wherein the at least one layer of the stack is made of
2 any one of: SiN or SiON.

1 15. The coupler as per claim 9, wherein the waveguide is made of SiN.

1 16. The coupler as per claim 8, wherein the layers decrease and increase according to
2 a grading function that is any one of: a parabolic, exponential, sine, cosine, or sinh
3 function.

1/13

*FIG. 1*

2/13

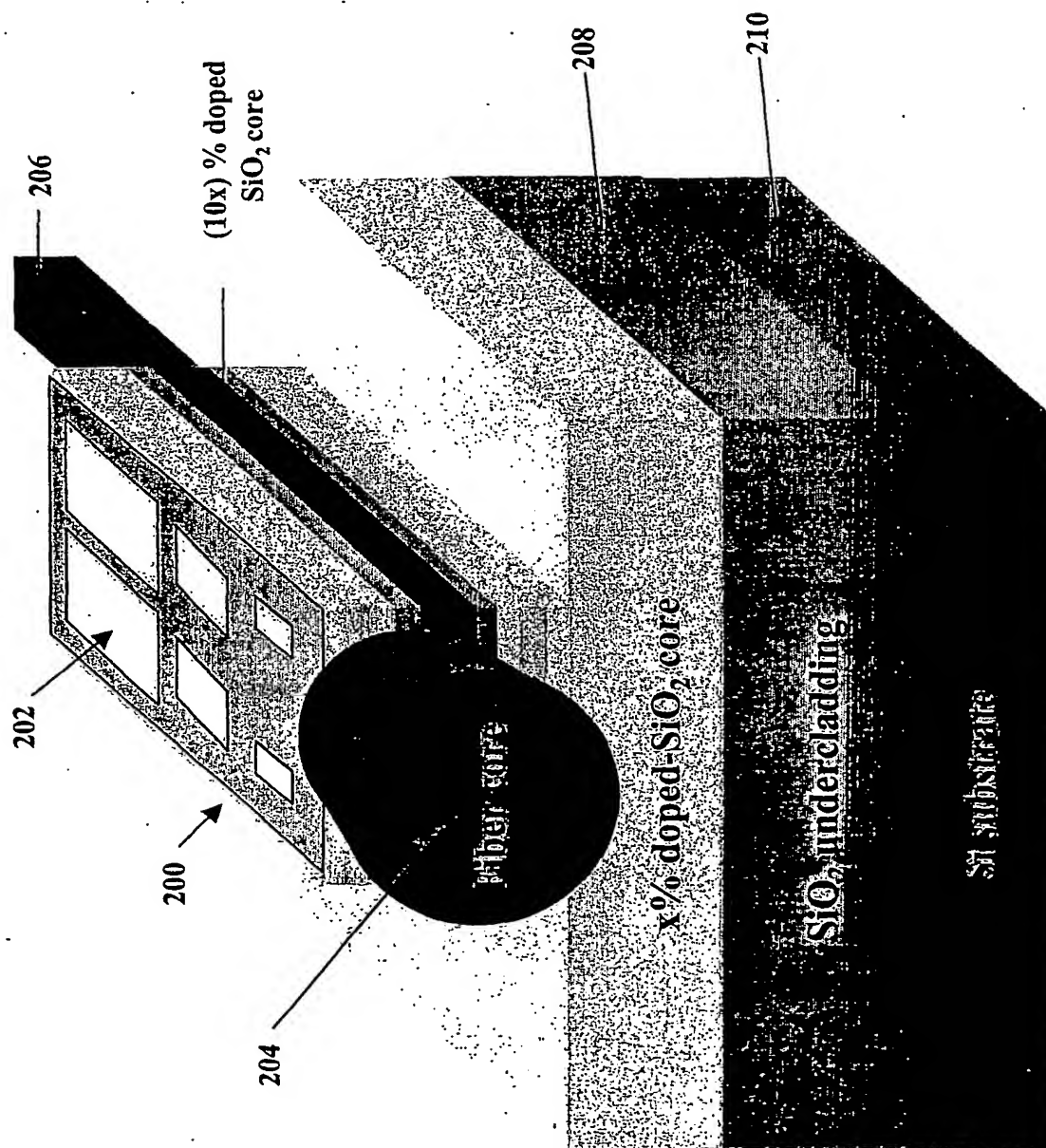


FIG. 2A

3 / 13

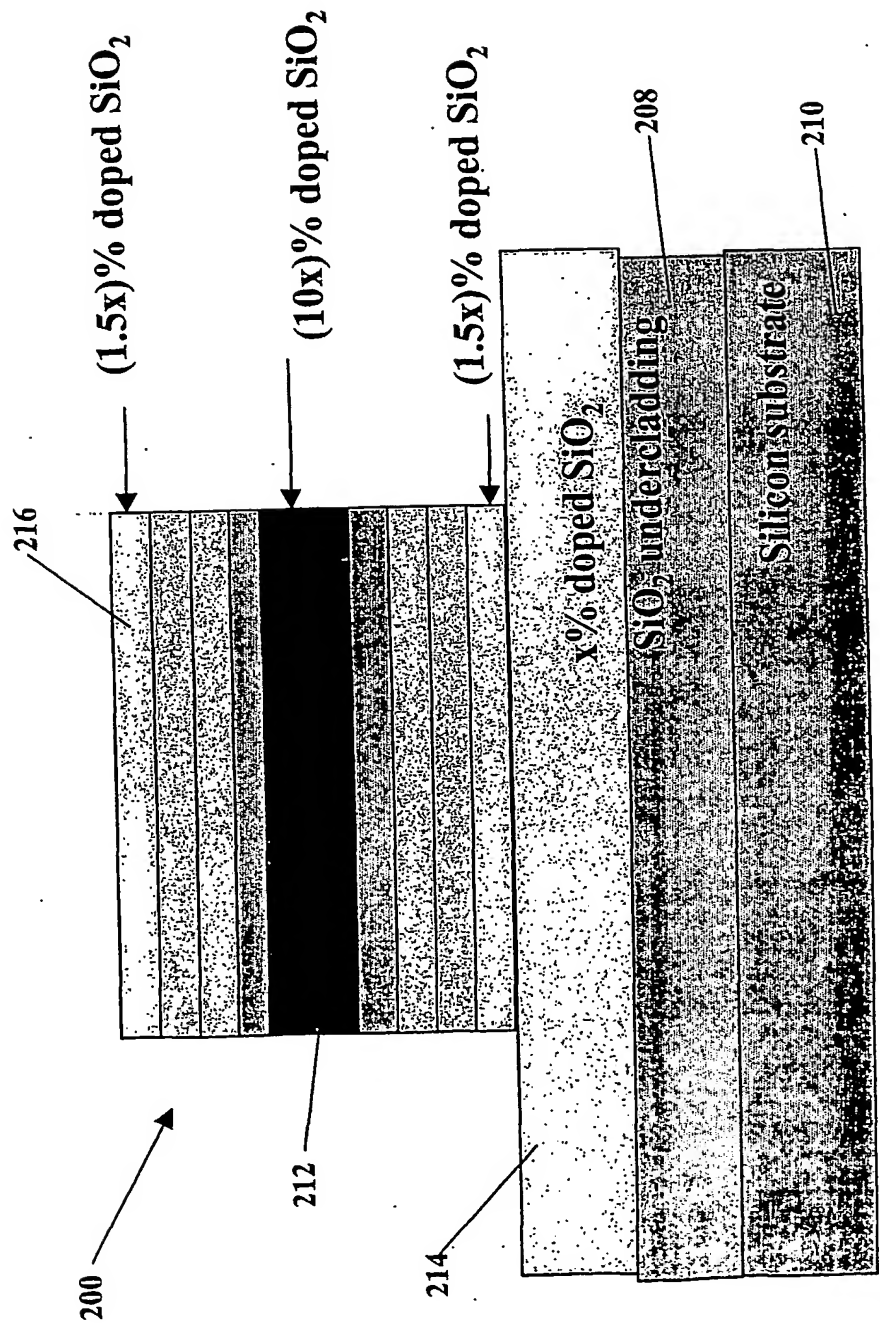


FIG. 2B

4/13

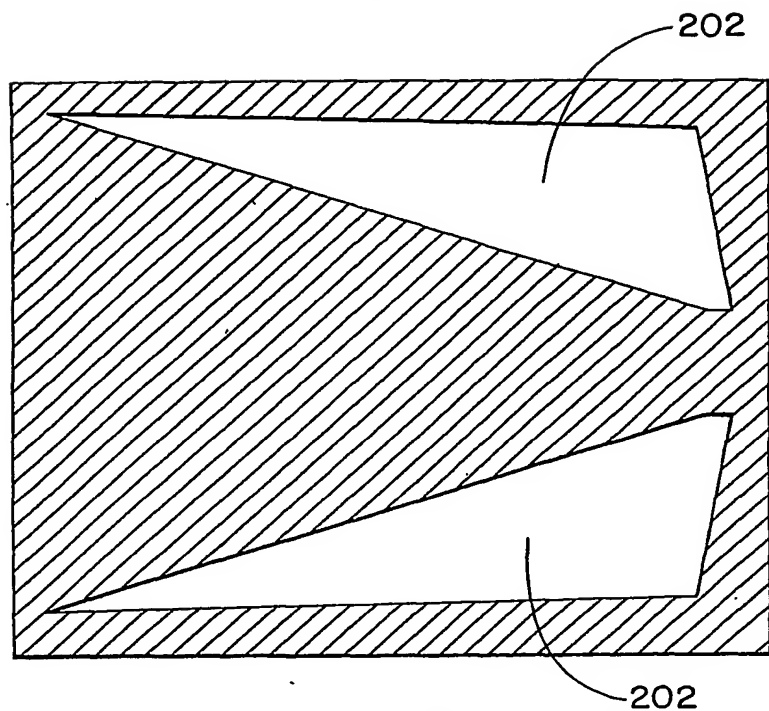


FIG. 2C

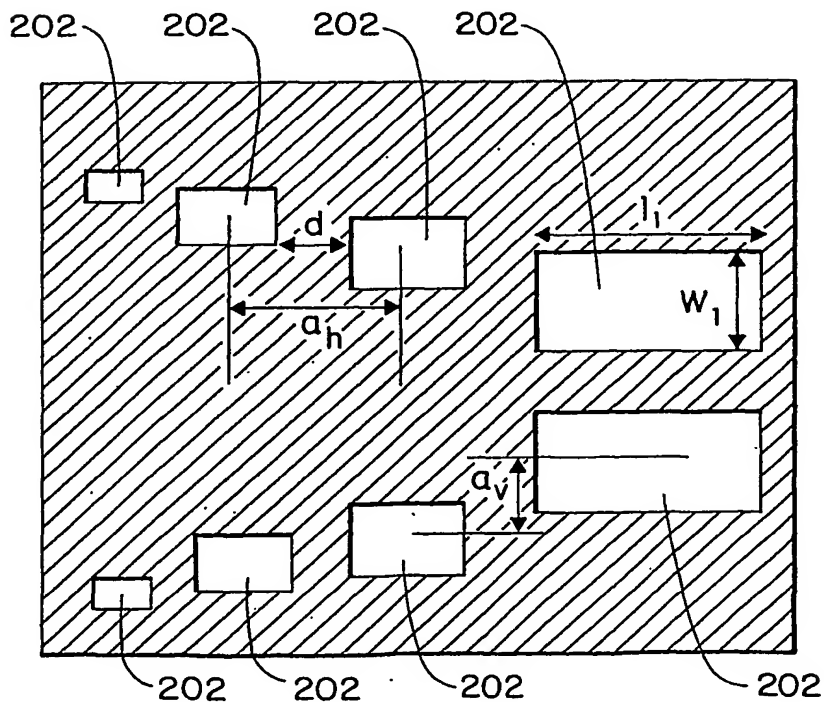


FIG. 2D

SUBSTITUTE SHEET (RULE 26)

5 / 13

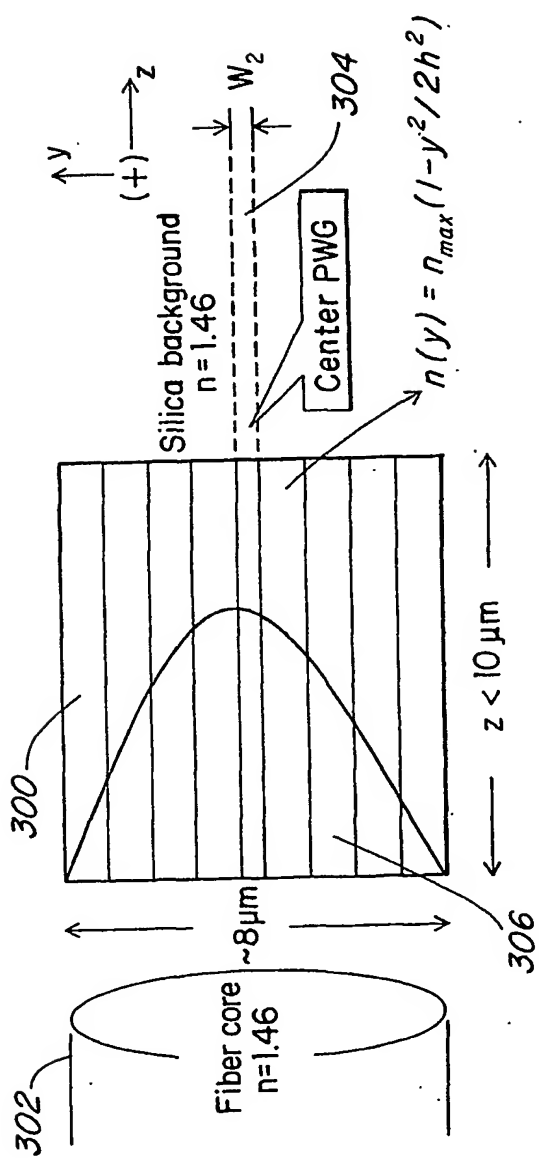


FIG. 3A

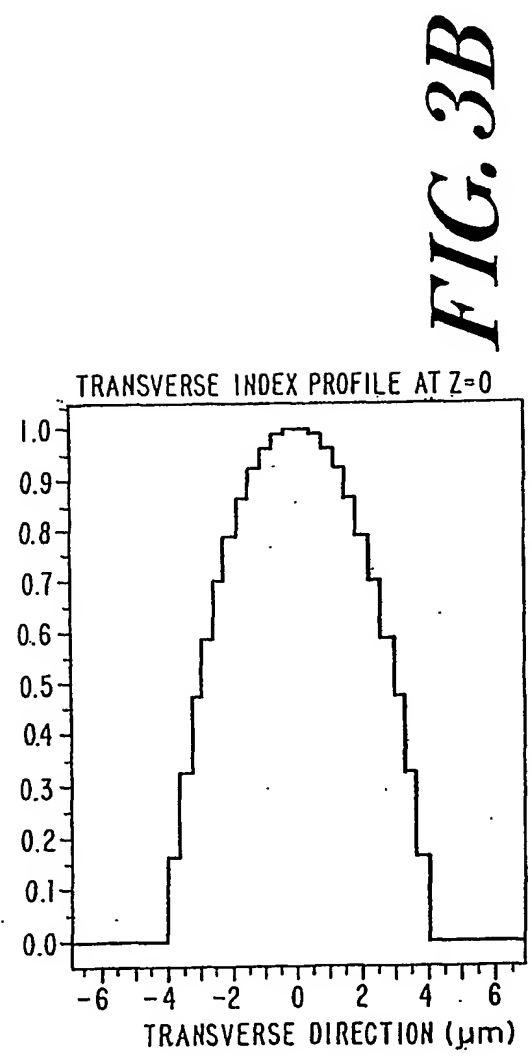
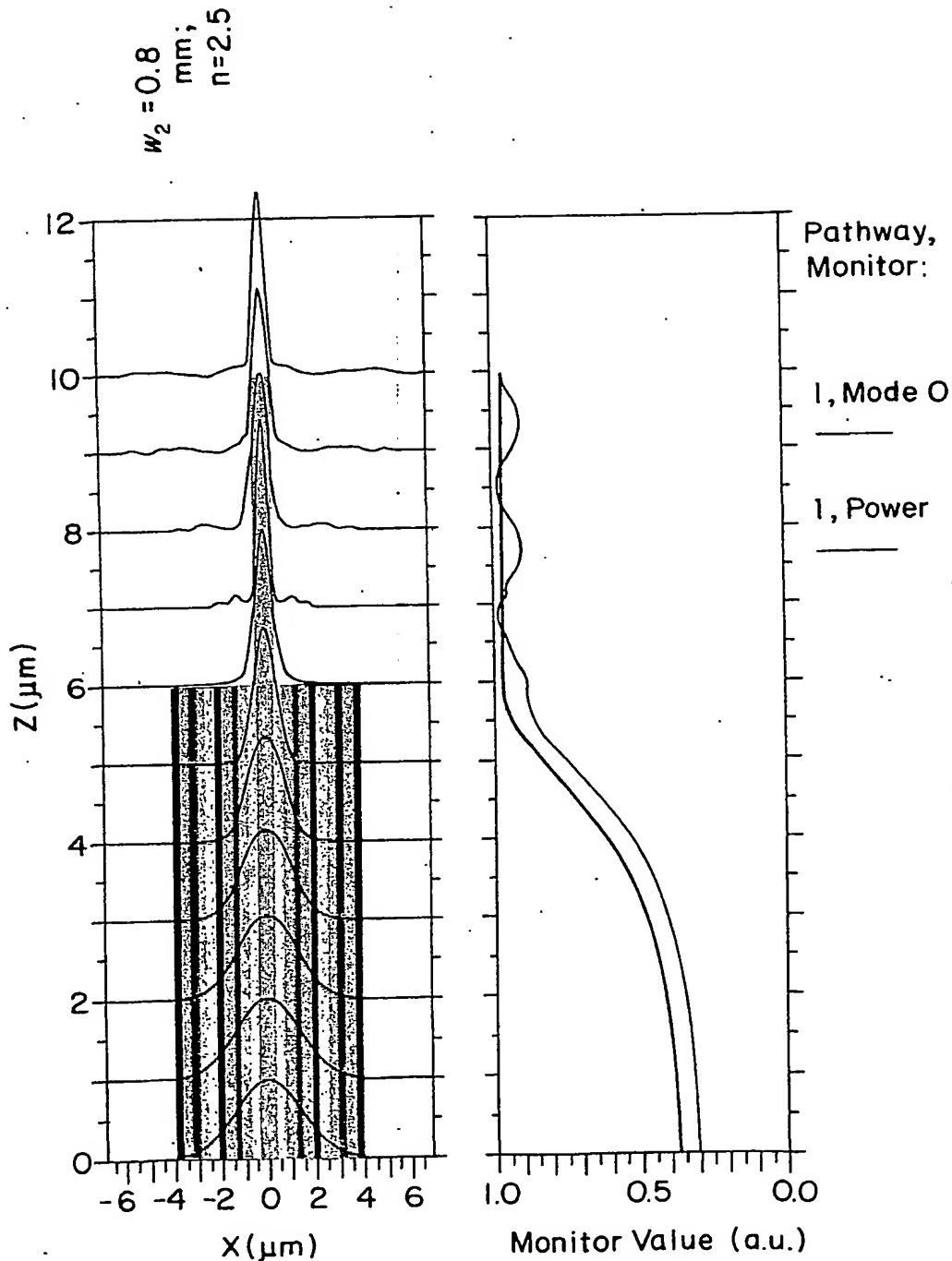


FIG. 3B

6/13

Vertical confinement- Result for $n_{\max}=2.5$



Simulation shows coupling efficiency of 0.83 at $L=6\text{mm}$

FIG. 3C

SUBSTITUTE SHEET (RULE 26)

7/13

Vertical confinement- Results for $n_{\max}=2.0$

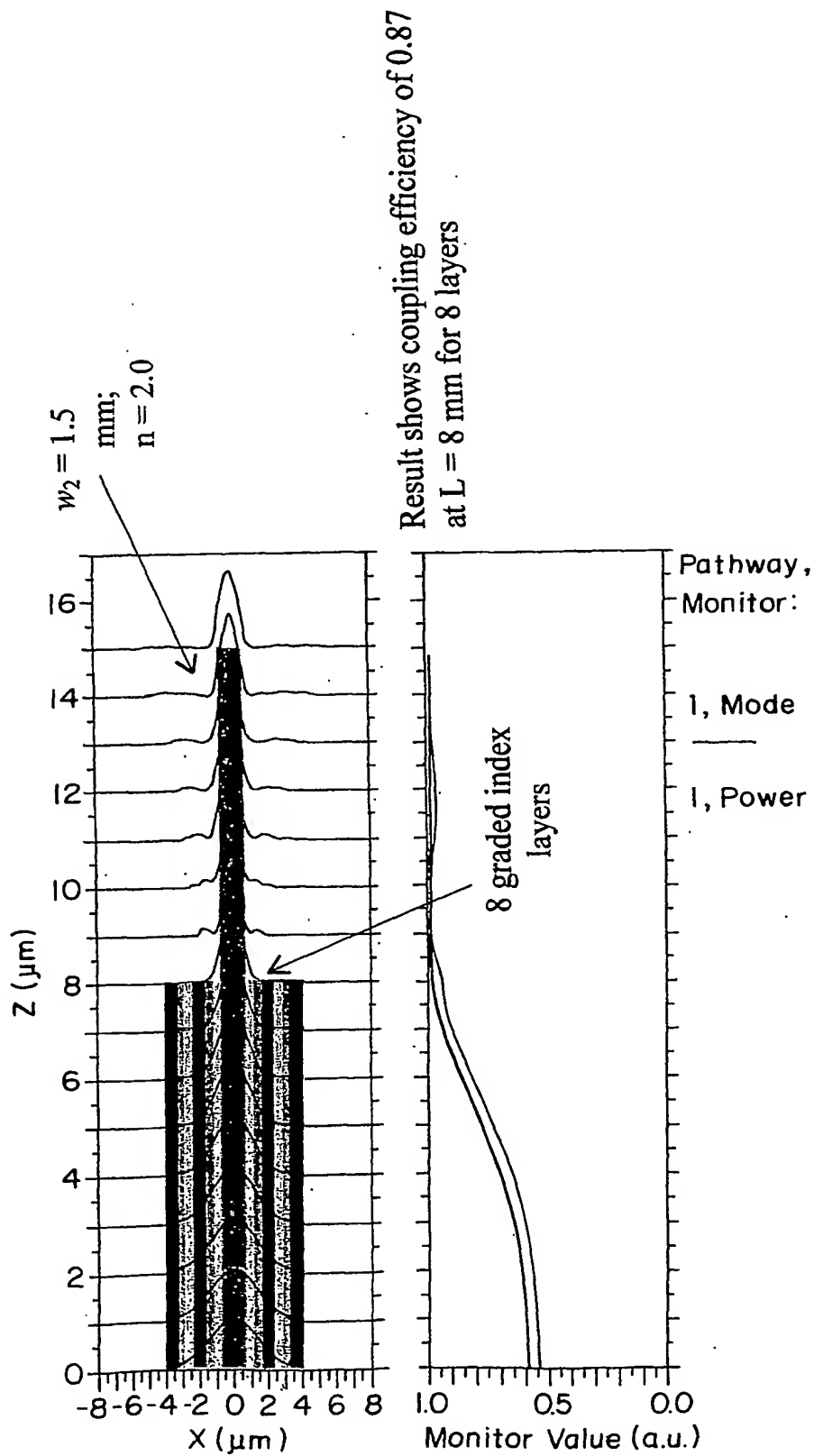


FIG. 3D

8/13

Vertical confinement- Results for $n_{\max}=2.0$

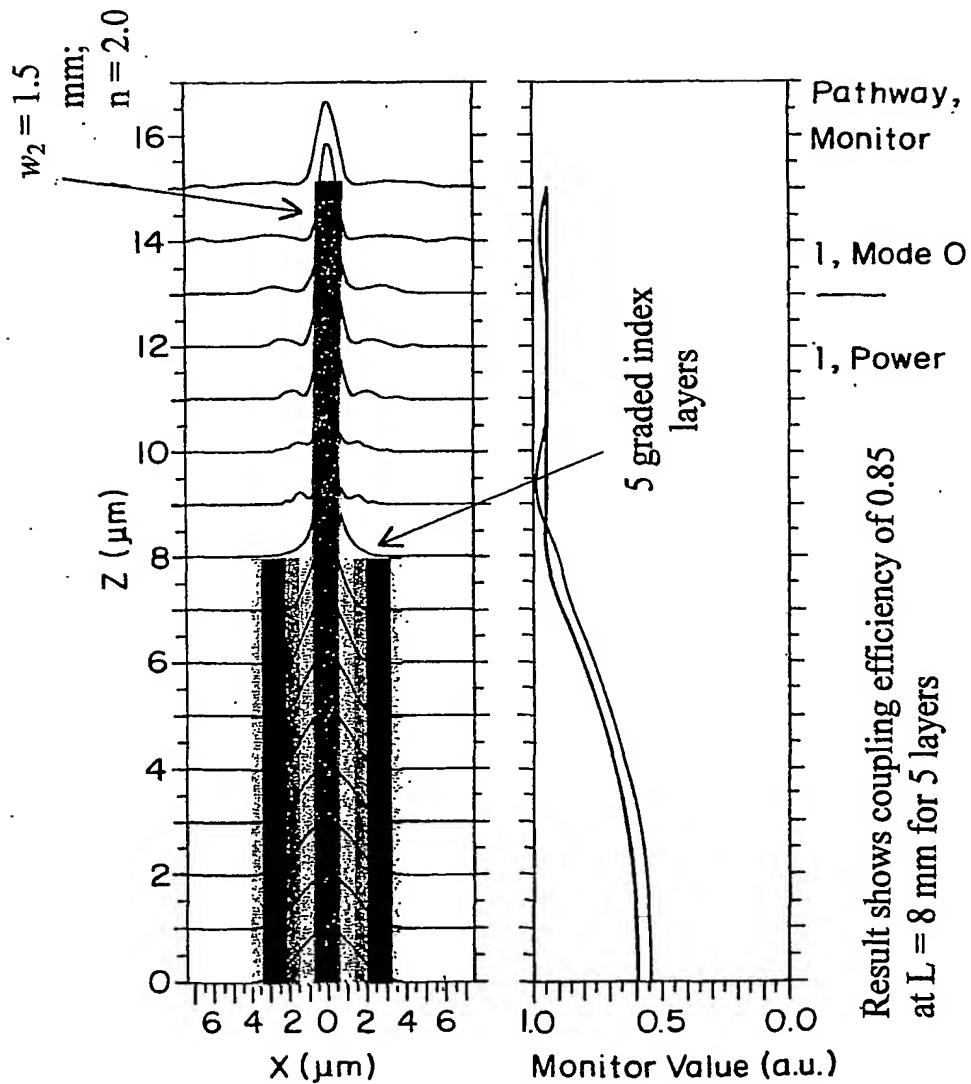


FIG. 3E

SUBSTITUTE SHEET (RULE 26)

9/13

Vertical confinement- FDTD result for

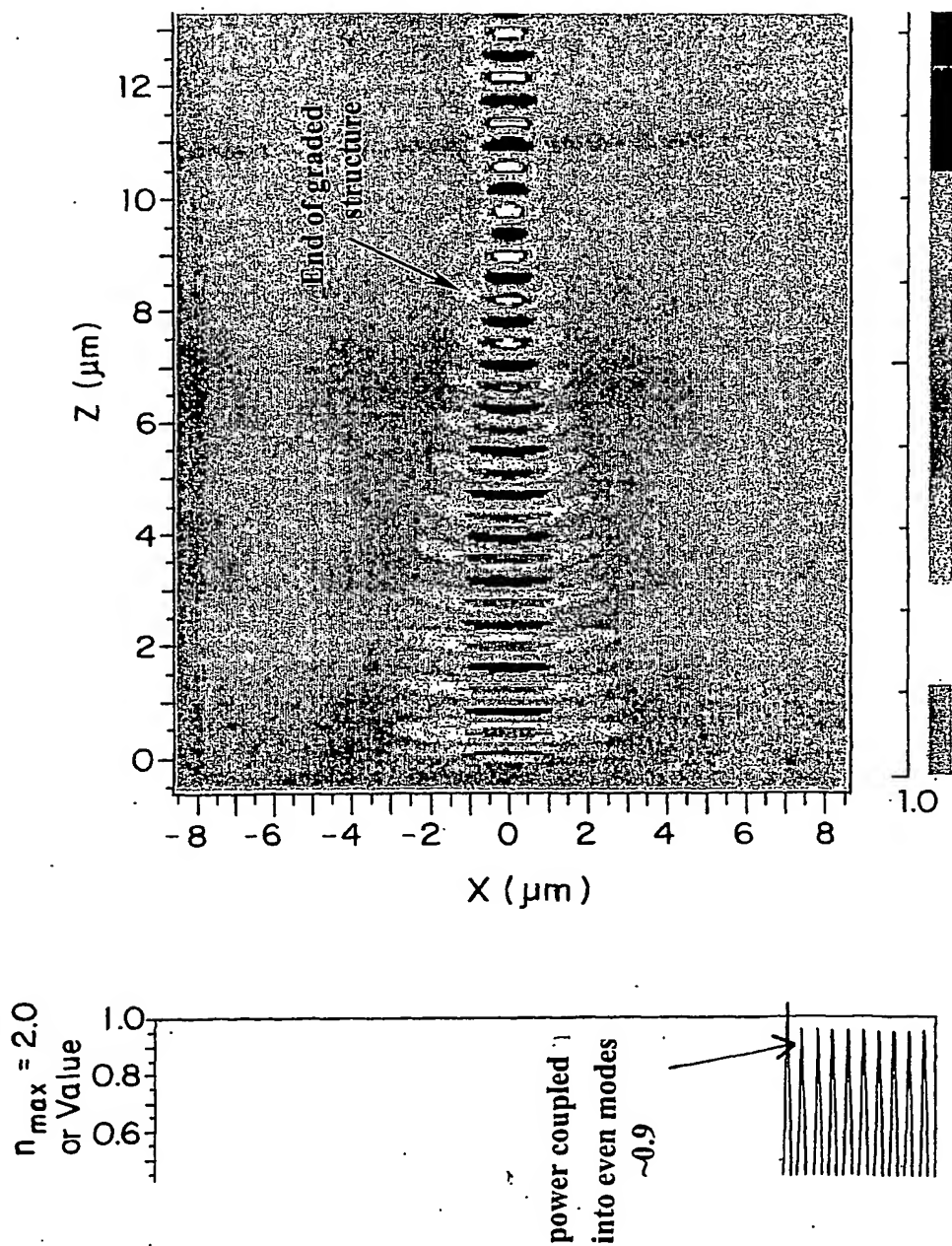


FIG. 3F

SUBSTITUTE SHEET (RULE 26)

10/13

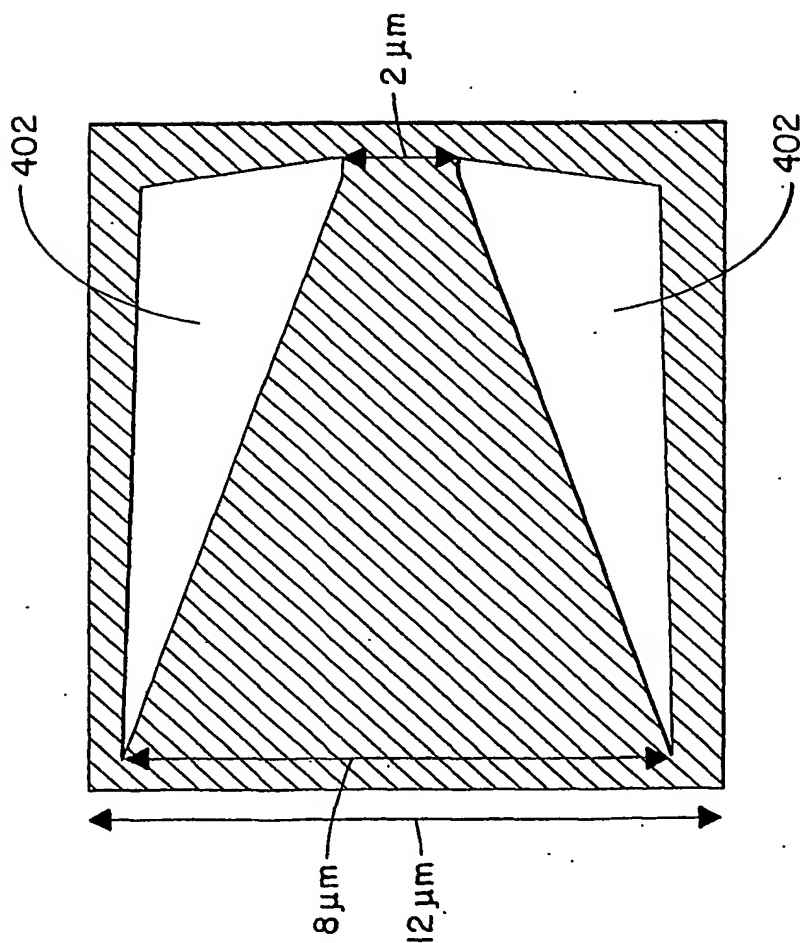


FIG. 4A

11/13

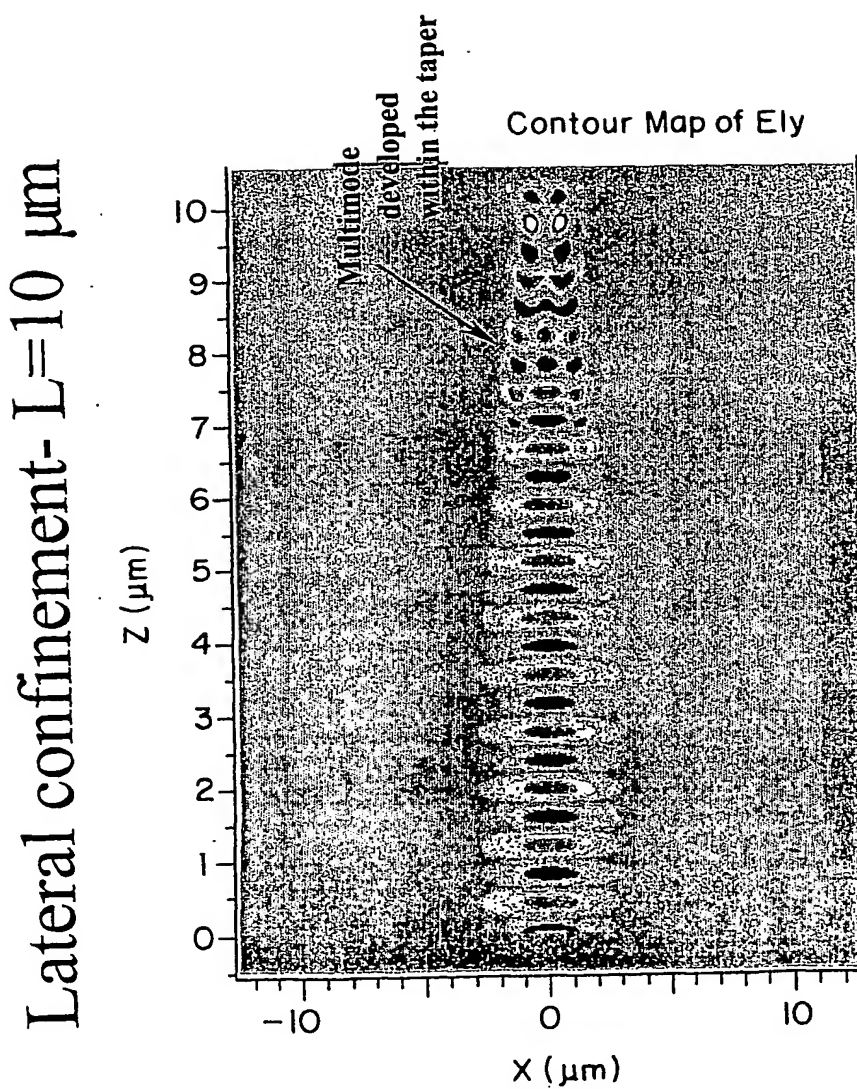


FIG. 4B

12 / 13

Lateral confinement- $L = 25 \mu\text{m}$

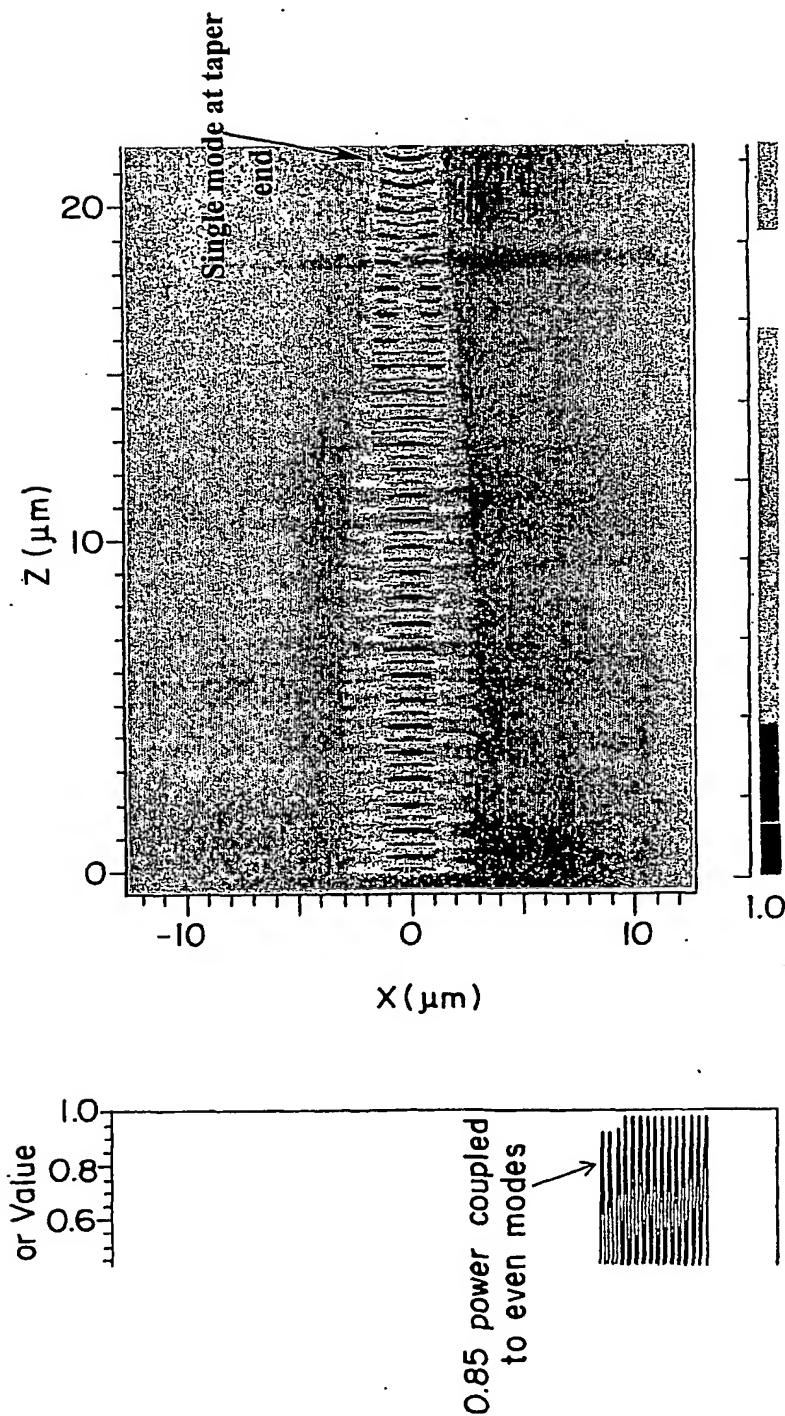


FIG. 4C

13 / 13

Lateral confinement- $L = 25 \mu\text{m}$ - Inverse

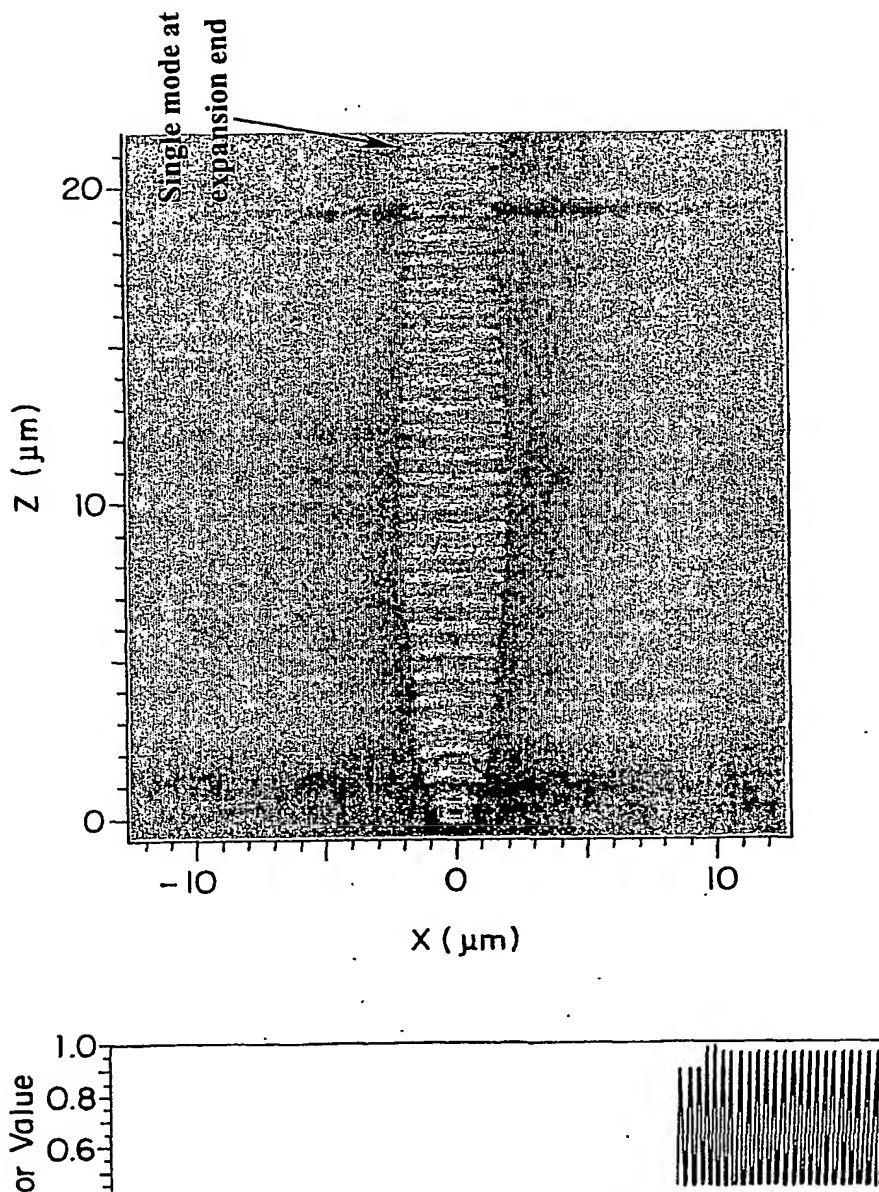


FIG. 4D

SUBSTITUTE SHEET (RULE 26)

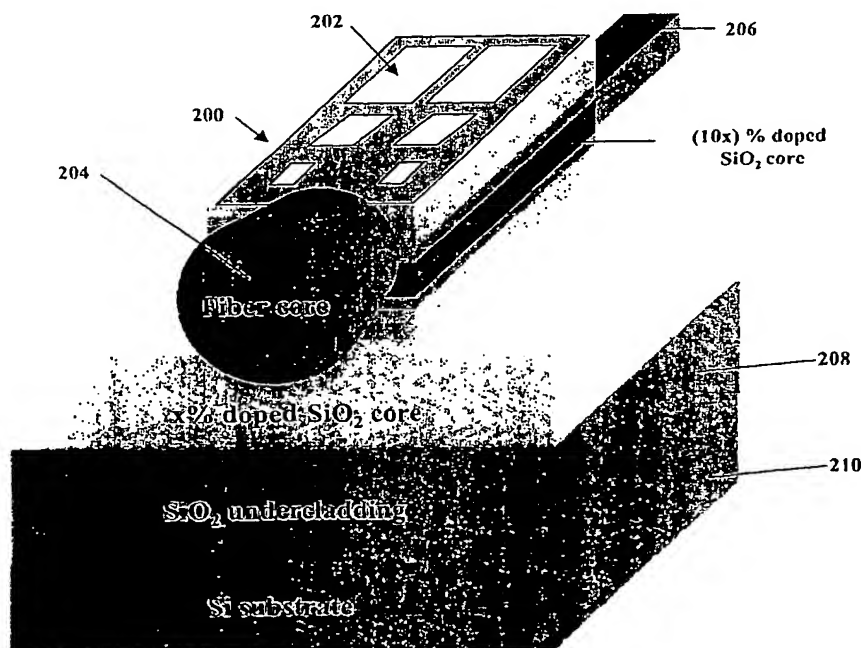
(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau(43) International Publication Date
14 November 2002 (14.11.2002)

PCT

(10) International Publication Number
WO 02/091051 A3(51) International Patent Classification⁷: **G02B 6/30, 6/12**(21) International Application Number: **PCT/US02/14386**(22) International Filing Date: **8 May 2002 (08.05.2002)**(25) Filing Language: **English**(26) Publication Language: **English**(30) Priority Data:
60/289,627 **8 May 2001 (08.05.2001) US**(71) Applicants: **MASSACHUSETTS INSTITUTE OF TECHNOLOGY** [US/US]; 77 Massachusetts Avenue, Cambridge, MA 02139 (US). **KIMERLING, Lionel, C.** [US/US]; 369 Strawberry Hill Road, Concord, MA 01742 (US). **HAUS, Hermann A.** [US/US]; 3 Jeffrey Terrace, Lexington, MA 02420 (US). **WADA, Kazumi** [JP/US]; 23 Hill Street, Lexington, MA 02421 (US). **JOHNSON, Steven, G.** [US/US]; 521 Longmeadow Circle, St. Charles, IL 60174 (US). **MANOLATOU, Christina** [GR/US]; 305 Memorial Drive, Cambridge, MA 02139 (US). **MICHEL,****Jurgen** [US/US]; 500 Summer Street, Arlington, MA 02474 (US). **NGUYEN, Trinh, Tranh** [VN/US]; 20700 San Jose Hills Rd, #163, Walnut, CA 91789 (US).(72) Inventor: **AGARWAL, Anuradha, M.**; 105 Hickory Road, Weston, MA 02493 (US).(74) Agents: **CONNORS, Matthew, E. et al.**; Samuels, Gauthier & Stevens, LLP., Suite 3300, 225 Franklin Street, Boston, MA 02110 (US).(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZM, ZW.(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR,

[Continued on next page]

(54) Title: **VERTICALLY AND Laterally CONFINED 3D OPTICAL COUPLER**

(57) Abstract: An on-chip silicon-based optical coupler (200) used to guide light from an optical fiber (204) to a waveguide (206). The incoming wave is confined vertically by stacks of graded index materials. In the lateral direction, a linear taper formed by etched holes (202) or trenches confines the wave.

WO 02/091051 A3

WO 02/091051 A3



GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent
(BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR,
NE, SN, TD, TG).

(88) Date of publication of the international search report:
30 May 2003

Published:

— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

INTERNATIONAL SEARCH REPORT

intl. Application No

PCT/US 02/14386

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G02B6/30 G02B6/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0 731 367 A (AT & T CORP) 11 September 1996 (1996-09-11) column 2, line 55 - column 3, line 3 column 4, line 51 - line 58 column 6, line 4 - line 6 column 9, line 14 - column 10, line 42 figure 8	1-16
Y	US 4 737 015 A (ISHIDA KOJI ET AL) 12 April 1988 (1988-04-12) column 1, line 45 - column 2, line 12 column 4, line 24 - line 54; figure 3	1-16



Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

* Special categories of cited documents:

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

X document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

Y document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

* & * document member of the same patent family

Date of the actual completion of the international search

7 November 2002

Date of mailing of the international search report

15/11/2002

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Ciarrocca, M

INTERNATIONAL SEARCH REPORT

Int. Application No.

PCT/US 02/14386

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No. ~
A	WEISSMAN Z ET AL: "MODES OF PERIODICALLY SEGMENTED WAVEGUIDES" JOURNAL OF LIGHTWAVE TECHNOLOGY, IEEE. NEW YORK, US, vol. 11, no. 7, July 1993 (1993-07), pages 1831-1838, XP000828051 ISSN: 0733-8724 page 1836, right-hand column, last paragraph	9
A	US 4 999 686 A (AUTIER PHILIPPE ET AL) 12 March 1991 (1991-03-12) column 7, line 24 - line 27 column 6, line 46 - last line; figures 6,7	1,9
A	US 6 160 927 A (LECLERC DENIS ET AL) 12 December 2000 (2000-12-12) column 7, line 10 - line 15; figures 7B,8	1
A	PATENT ABSTRACTS OF JAPAN vol. 013, no. 467 (P-948), 23 October 1989 (1989-10-23) -& JP 01 183603 A (MITSUBISHI ELECTRIC CORP), 21 July 1989 (1989-07-21) abstract	1
A	US 5 175 788 A (MIURA KAZUNORI ET AL) 29 December 1992 (1992-12-29) column 2, line 3 - line 28 column 4, line 51 - line 59; figure 4 figures 7A,7B	1

information on patent family members

-Int Application No -

PCT/US 02/14386

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
EP 0731367	A	11-09-1996	US 5629999 A	13-05-1997
			DE 69609646 D1	14-09-2000
			DE 69609646 T2	28-12-2000
			EP 0731367 A2	11-09-1996
			JP 3296711 B2	02-07-2002
			JP 8262244 A	11-10-1996
US 4737015	A	12-04-1988	JP 60114811 A	21-06-1985
US 4999686	A	12-03-1991	FR 2633401 A1	29-12-1989
			DE 68915343 D1	23-06-1994
			DE 68915343 T2	01-09-1994
			EP 0349038 A1	03-01-1990
			JP 2110405 A	23-04-1990
			JP 6075127 B	21-09-1994
US 6160927	A	12-12-2000	FR 2760850 A1	18-09-1998
			EP 0864886 A1	16-09-1998
			JP 10268151 A	09-10-1998
JP 01183603	A	21-07-1989	NONE	
US 5175788	A	29-12-1992	JP 3288102 A	18-12-1991

**This Page is Inserted by IFW Indexing and Scanning
Operations and is not part of the Official Record**

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

☒ **BLACK BORDERS**

☐ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**

☐ **FADED TEXT OR DRAWING**

☐ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**

☐ **SKEWED/SLANTED IMAGES**

☐ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**

☐ **GRAY SCALE DOCUMENTS**

☐ **LINE(S) OR MARKS ON ORIGINAL DOCUMENT**

☐ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**

☐ **OTHER:** _____

IMAGES ARE BEST AVAILABLE COPY.

As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.